Space Storable Hybrid Rocket Technology Development

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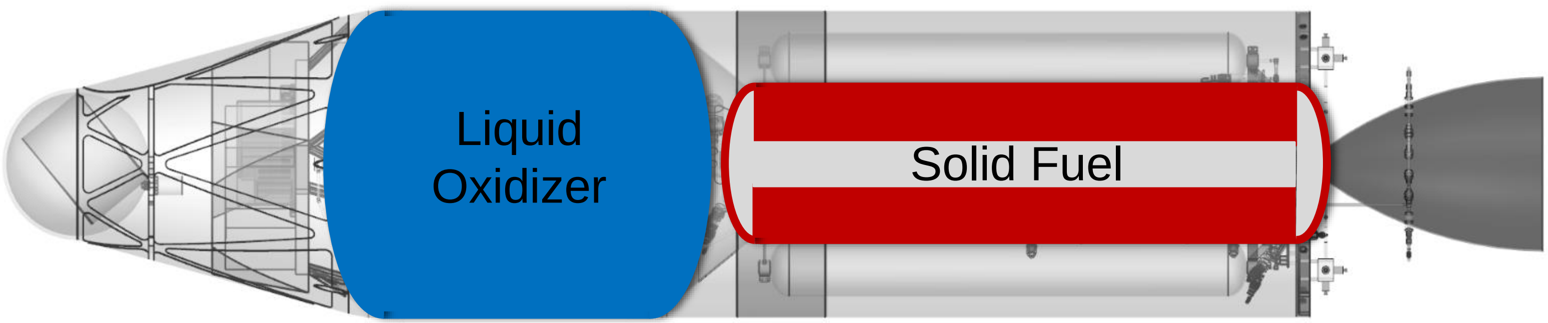
Agenda

- Introduction to Hybrid Propulsion
- A Potential Hybrid Mars Ascent Vehicle (MAV)
- MAV Technology Development
  - New fuel formulation
  - Fuel processing
  - Subscale testing
  - Full scale testing
  - Hypergolic ignition testing
  - Future work and remaining challenges
- SmallSat Technology Development
- Other Applications
- Summary/Conclusion

Introduction to Hybrid Propulsion

- Hybrid rockets utilize propellants in different phases.
- Benefits include
  - Low temperature storage and operation
  - High performance (similar to liquid propulsion) with reduced complexity
  - Capable of multiple starts

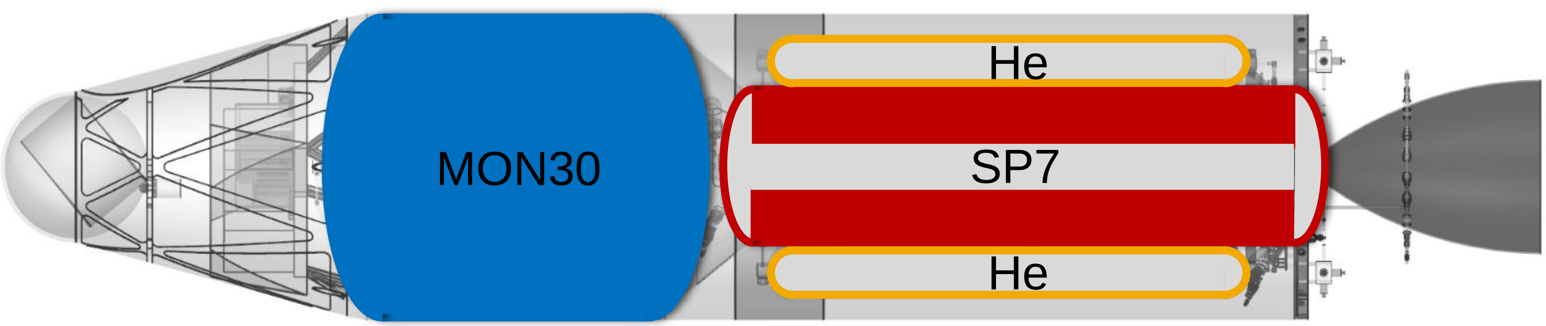


A Hybrid Mars Ascent Vehicle

- Recent Development Timeline:
  - 2014: Reopened trade space to all propulsion options
  - 2015: Narrowed options to TSTO Solids, SSTO Liquid, SSTO Hybrid
  - 2016: Hybrid design selected for future development with the support of the Mars Program Office
  - 2016: Point of Departure Review – design freeze
  - 2017-present: Technology maturation of hybrid propulsion technologies

Hybrid Mars Ascent Vehicle Concept

- Oxidizer: MON30 (70% N_2O_4 and 30% NO)
  - Freezing point ~-80 C
  - LITVC
- Fuel: Wax-based SP7
  - Low glass transition (rotor phase transition at ~40C, but glass phase could not be detected on DSC down to -90 C)
  - Possible inclusion of hypergolic particles in fuel
- Helium Pressurization and cold gas RCS



MAV Technology Development

- MAV Technology Development
  - New fuel formulation
  - Fuel processing
  - Subscale testing
  - Full scale testing
  - Hypergolic ignition testing
  - Future work and remaining challenges

New Fuel Formulation & Processing

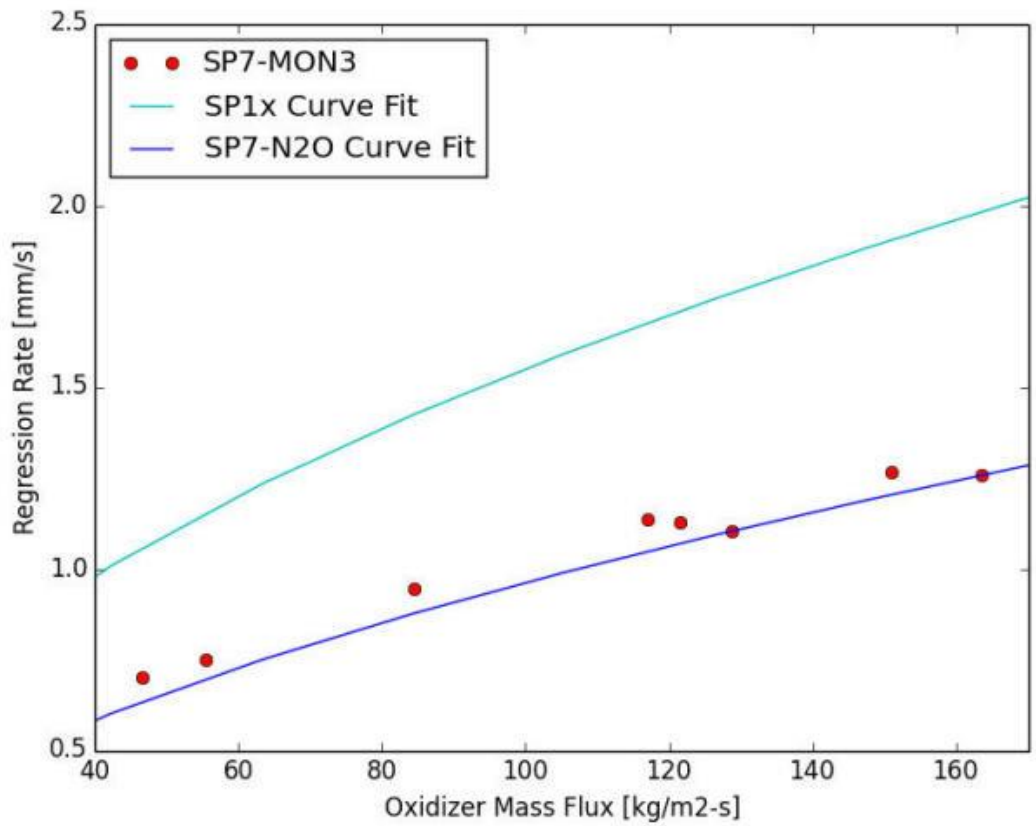
- SP7 was developed for this application
  - Wax based fuel
  - Desired survival over -100 C to 50 C temperature range
  - Comparison to paraffin: similar performance (Isp), higher strength and decreased regression rate (thrust)
- Processing
  - Cannot spin cast – melted SP7 is too viscous
  - Fuel grains are currently cast in segments, oven cooled and machined to proper dimensions
  - One monolithic grain has been produced so far – testing has all been with segmented grains. No issues have been seen.

Subscale testing

- The curves indicate the regression rate behavior of the propellant combinations.

$$\dot{r} = a\, G_{ox}^{n}$$

- The red rots indicate successful subscale tests of SP7/MON3.
- They track the SP7/N2O line fairly closely (albeit a bit higher).



Brian J. Evans and Arif M. Karabeyoglu. "Development and Testing of SP7 Fuel for Mars Ascent Vehicle Application", 53rd AIAA/SAE/ASEE Joint Propulsion Conference, 2017. (AIAA 2017-4831)

Full Scale Testing

- Testing is ongoing at two subcontractors
- Objectives: full scale regression rate data, long duration tests, restart, LITVC demonstration

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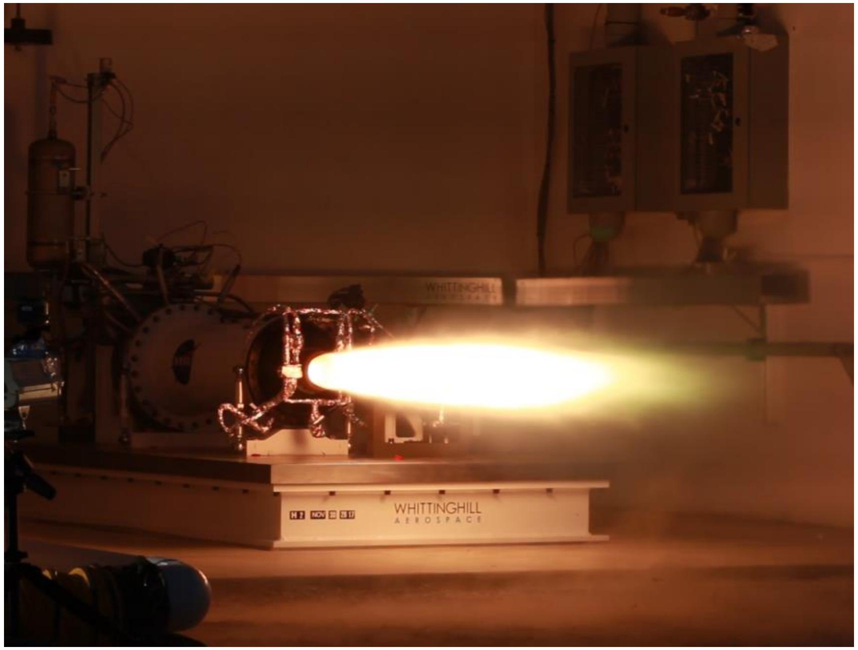

Whittinghill Aerospace

Predecisional information, for planning and discussion only

Hypergolic Ignition Testing

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Test #5-10
December 1st, 2017

MON-3
40 wt.% $NaNH_2$ in SP7
Front section: 90 wt.% $NaNH_2$ in SP7
Panasonic 4K at 29 fps, resolution: 3840x2160

Dr. T. Pourpoint (timothee@purdue.edu)
Purdue University - 2017

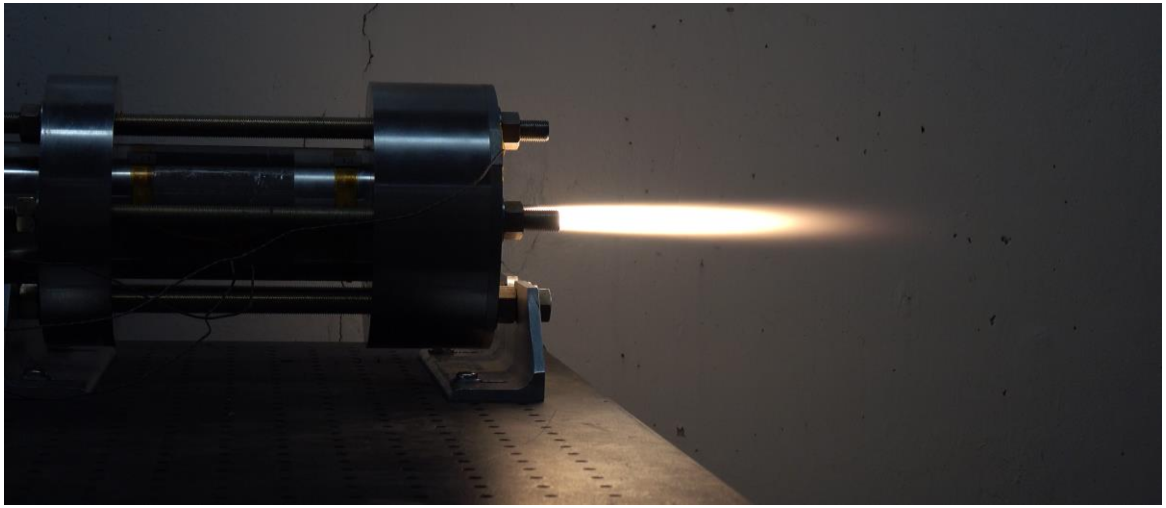
PURDUE UNIVERSITY

Future Work and Challenges

- Qualification
  - Testing up to this point has been R&D at Earth conditions
- CTE mismatch
  - An evaluation of CTE mismatch of all materials in the motor will need to be completed
  - Full scale thermal cycling of the motor and hotfire testing of the cycled motors
    - Subscale motors were often cooled.
- Incorporation of hypergolic materials.

SmallSat Technology Development

- PMMA/gaseous O_2 (non-toxic) is being tested at JPL.
  - Reference mission is Mars OI with multiple Phobos/Demos flybys
- More than 50 tests have been completed to investigate different propellant options.
  - Selected combination: 32 tests including 10 tests of over 60 s
  - Maximum test duration: 95 s
  - Multiple restarts: 5



Other Applications

- ISRU
  - The hybrid MAV propellants lend itself to ISRU.
  - The power story did not close during the original study (2014). As new batteries become available, it would be interesting to evaluate this option again.
  - Hotfire testing of paraffin wax fuel grains with an oxidizer made up of O_2 with varying concentrations of CO_2 was completed to determine the purity requirements that would be imposed on the conversion of CO_2 to O_2.
- Outer planet orbit insertion
  - Cold temperature storage and operation of the propellants enable reduced heating and therefore power requirements

Summary/Conclusions

- Hybrid rocket propulsion is a promising candidate for space storable applications because of its
  - Advantages associated with this propulsion technology are leading to investments in its development within NASA.
- Large scale testing is currently being completed to mature a wax-based fuel/MON propellant combination for a potential Mars Ascent Vehicle.
  - No show stoppers have been identified and the testing continues to yield improvements in performance and stability.
- Hybrid motors using classical (slow burning) fuels are being considered for SmallSat propulsion.
- The high specific impulse and relatively high thrust enables large ΔV maneuvers such as orbit insertions.

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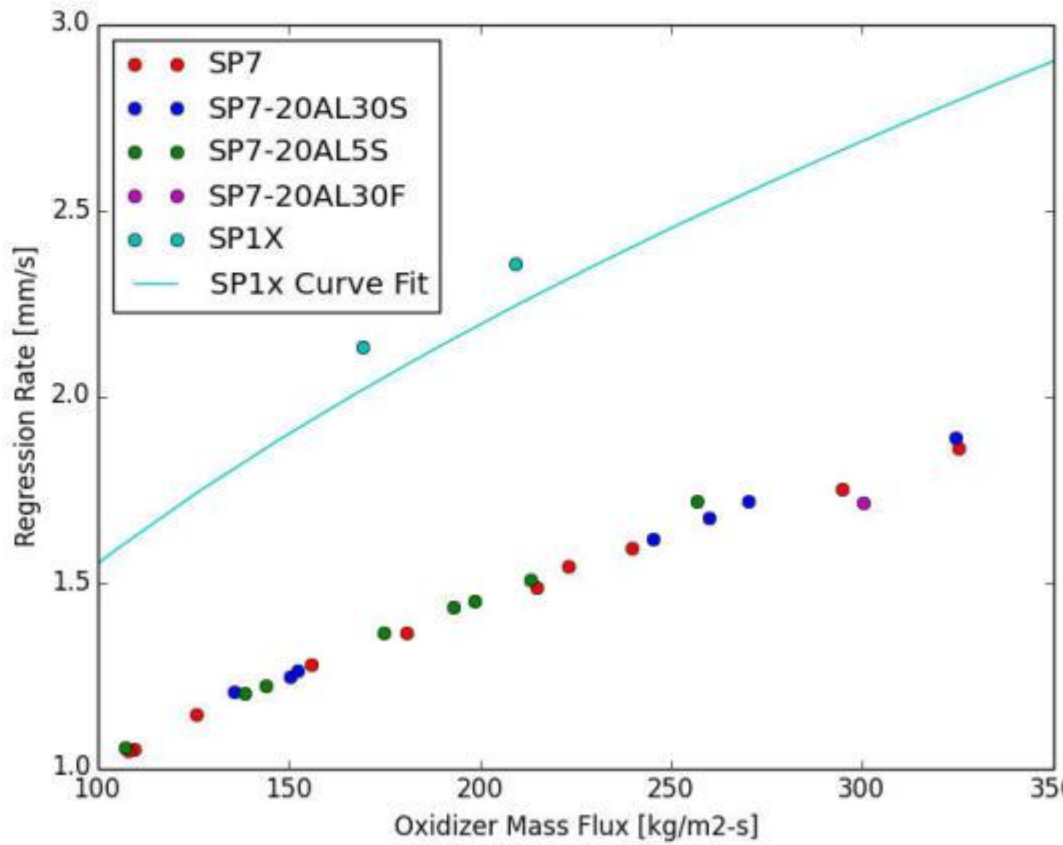
BACK UP

Subscale testing (aluminized fuel)

- The regression rate curve for SP7/N2O included data from tests with aluminized fuel grains.
- Different particle sizes were investigated.
- No marked difference between the aluminized and neat SP7 grains was observed.



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